FOREST INVENTORY AND ANALYSIS: WHAT IT TELLS US ABOUT WATER QUALITY IN ARKANSAS

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Abstract—Forests and forest activities have a significant impact on the amount and quality of surface water in Arkansas. Recognizing this important relationship between forests and water quality, we utilized the Forest Inventory and Analysis (FIA) data from Arkansas to better understand how forest land use in Arkansas has likely influenced the water quality in the State during the past 17 years. Five specific types of FIA information were considered to be important indicators of, or strongly correlated with, water quality: (1) the land area in forest cover, (2) age distribution of forests, (3) amount of harvesting and timber removal, 4) amounts of riparian forests and, 5) health and vigor of the Arkansas forests. Information from the FIA database suggests that water quality attributed to forest land use should have increased or at least remained the same over the past 17 years. These conclusions reflect an increased amount of forest lands within the State, increases in important riparian forest area in the Delta and Southwestern region, a general maturing of Arkansas forests, and increased growing-stock volumes during this time period. Timber removals in the State have increased, but any potentially negative water quality effects of forest harvesting have most likely been offset by increases in forest area and a general maturing of the resource.

INTRODUCTION

To examine what we might learn about the status of water quality or hydrology in Arkansas from what is known concerning the character, quantity, and distribution of forests in the State is the objective of this paper. Information concerning Arkansas forests was derived from the extensive database provided by the Forest Inventory and Analysis (FIA) Unit of the USDA Forest Service, Southern Research Station. Furthermore, it is our objective to discuss ways in which FIA might be implemented to provide more direct information useful for evaluating water quality in Arkansas.

In order to set the stage for the FIA and water-quality discussion, we first briefly review the basic relationships among forests, forest management, forest soils, water quality, and hydrology. While covering these topics could require several textbooks and consume a semester-long course, it is our intent to make some general statements and provide limited scientific support or examples, which will delineate the important issues and data to be covered in the evaluation.

IMPACT OF FORESTS ON SOIL AND WATER RESOURCES

Erosion

Annual soil erosion from forested lands is minimal and is commonly lower than erosion rates under most other land uses. Erosion from undisturbed and carefully managed forest lands in the United States has been reported to range from 0.05 to 0.10 tons per acre per year. Measured erosion rates from minimally disturbed forest lands rarely exceeded 0.25 tons per acre per year (Patric and others 1984). Based on a national survey in 1987, soil erosion from cropland was estimated to average about 3.8 tons per acre per year (USDA Soil Conservation Service 1989).

Research in the Ouachita Mountains of Arkansas reported soil erosion from harvested and undisturbed forests was in line with data reported from forests nationally (fig. 1). Miller and others (1988a) reported erosion from undisturbed forested watersheds averaged about 0.03 tons per acre per year, whereas rates from clearcut areas averaged about 0.10 tons per acre per year during the first 3 years following forest harvest when disturbances are the greatest.

There are a number of reasons why erosion rates are low in disturbed as well as undisturbed forests. Soils in forests, even after normal harvesting, generally have good ground cover in terms of plants and logging debris, which reduces velocity of water movement. Infiltration rates are also high unless the soil has been severely compacted. These characteristics prevent soil detachment and transport, the essential elements of the erosion process. However, if excessive soil exposure occurs and bare soil is exposed for prolonged periods, forest harvesting can increase erosion rates. Excessive compaction or disturbance, often caused by harvesting on saturated soils, will also reduce infiltration of rainfall and increase overland flow of water. The increased exposure of mineral soil and the increased flow of water over the soil surface increase the potential for soil erosion. Silvicultural activities such as burning or windrowing of slash shortly after harvesting reduce debris and plant material, and, thus, can increase erosion beyond what is commonly produced by harvesting alone.

It is generally accepted that differences in erosion rates between undisturbed and harvested forests are relatively small and short lived. Furthermore, land-use conversion

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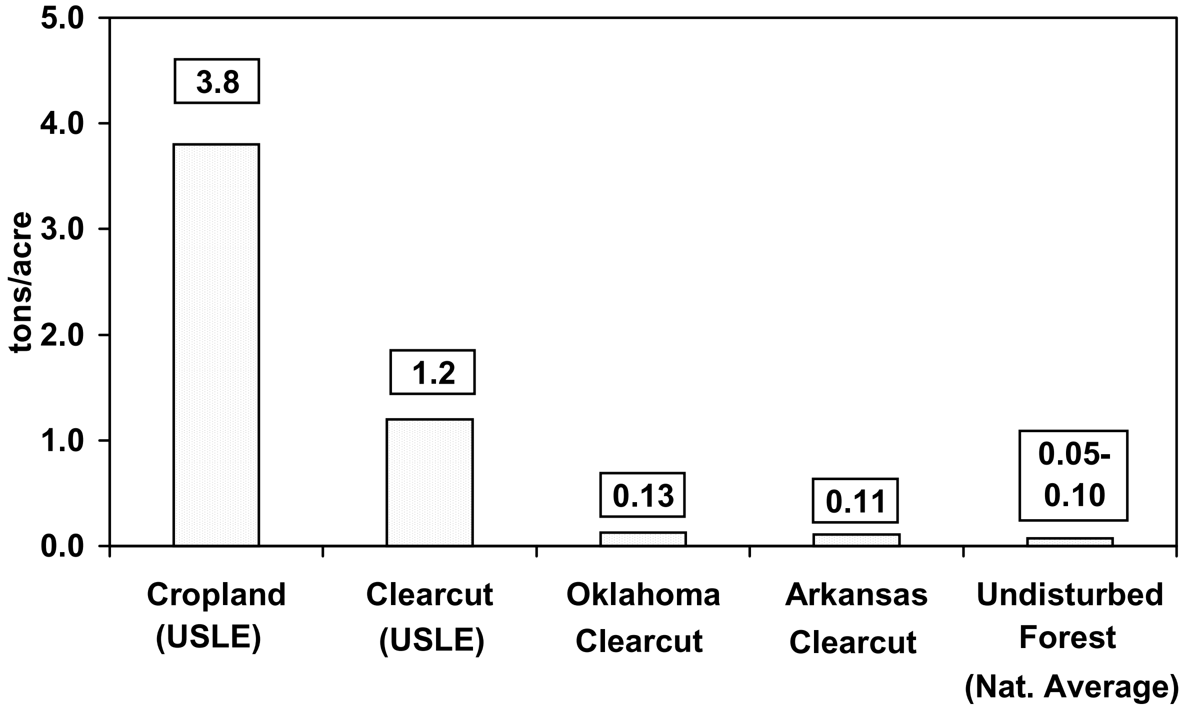

Figure 1—A comparison of annual soil loss from forests and croplands in the United States.

from forestry to cropping or cropping to forestry causes an order-of-magnitude, longer-term change in soil erosion rates. In comparison to forestry/cropping conversion, changes in erosion rates due to forest harvesting when followed by prompt forest regeneration cause relatively small changes in erosion and sedimentation.

Forest Harvest and Nutrient Losses

Undisturbed forests are very conservative regarding nutrient input and output (Jorgensen and Wells 1986). That is, input of nutrients from the atmosphere in the form of precipitation or dry deposition has a strong tendency to remain in the forest ecosystem once absorbed by plants within the ecosystem. Nutrient losses in stream flow from forests are generally small by comparison to the input. Consequently, the concentration as well as total nutrient losses associated with forest streams is usually low. Low levels of nutrients in stream flow are one indicator of high water quality. Low suspended sediment concentrations and cool temperatures are other characteristics of high quality stream flow.

Forest disturbance such as harvesting, burning or a land-use conversion will normally increase the losses of nutrients from forested watersheds through stream flow. Nutrient concentrations as well as the total annual losses of nutrients increase with the level of disturbance. Forest fertilization has also been shown to increase the output of nutrients, primarily nitrogen, in stream flow. Fortunately, the effect of forest disturbance on nutrient losses is relatively small and short lived when rapid forest regeneration occurs. Furthermore, when acceptable application rates and methodologies are utilized, forest fertilization of plantations and mature forests has short-term effects on stream nutrients because forests are effective at retaining added nutrient input.

Nutrients of importance to those interested in water quality and forest productivity include nitrogen, phosphorus, potassium, calcium, and a few others depending on special site characteristics. Nutrient movement in stream flow may occur when soluble nutrients such as nitrate-nitrogen and calcium are in solution and move freely with water through the soil. Other nutrients, primarily phosphorus, are not readily soluble and cannot move in solution with water. Phosphorus is strongly adsorbed onto soil particles. Therefore, the greatest percentage of phosphorus losses in stream flow is found when erosion occurs and sediment moves with stream flow.

Losses of nitrogen and phosphorus, as shown by comparisons of stream chemistry in harvested and undisturbed small forested watersheds in the Arkansas Ouachita Mountains (table 1), reflect these general trends in nutrient movement (Scoles and others 1995). Changes in

Table 1— Nutrient levels in stormflow after harvesting in nine Arkansas watersheds

	Uncut		Clearcut	
Year	Nitrate N	Total P	Nitrate N	Total P
	- - - - - - - - - - Pounds per acre - - - - - - - - - - -			
1981	0.08	0.05	1.18	0.29
1982	.01	.05	.08	.20
1983	.10	.13	.22	.25
1984	.19	.06	.25	.10

nutrient loads were small following the 1981 harvest treatments. Nutrient loads returned to control levels soon after harvest. Changes in nutrient losses following moderate controlled burning or forest fertilization treatments should also be expected to be minor and short lived. However, inclusion of the burning of logging debris with hot fires shortly after harvesting can elevate the nutrient losses above those found with only forest harvesting.

Good comparisons of nutrient losses following conversion of forests to other major land uses are not available. However, conversion from forest to cropping, for example, would involve significant changes in nutrient losses to streams due to a number of natural and management-related factors. These types of changes would likely be large and long term in comparison to those caused by forest management.

Forest Roads and Erosion

Forest roads pose an erosion threat because they are, by default, designed to expedite water movement. First, soils on road surfaces and back slopes may be maintained or remain in a bare or near-bare condition for extended periods of time. Soil particles are therefore continuously exposed to rainfall energy and possible detachment. Second, road drainage systems are specifically designed to efficiently transport water and its suspended sediment load from roads. In many cases, road runoff is directed to natural drains or streams. Where streams and roads cross, sediment can easily be displaced in streams unless diverted to more desirable locations.

Rates of erosion from forest roads are a function of many factors including soils, slopes, back slope design, surfacing materials, amount of road use, timing of use, road maintenance, topographic placement, and the type and placement of water control structures. Research on forest road erosion in Arkansas shows that the amount of sediment delivered to streams from roads can be significantly reduced when best management practices are used (Miller and others 1985). However, the amount of sediment produced and delivered to forest streams from an average forest road system on a watershed can easily exceed the amount of sediment produced as a result of all the silvicultural activities conducted on that watershed.

Because forest roads are a ready source of sediment, the presence or absence of forest roads and the extent of forest road use are good indicators of the potential for road sediments to enter forest streams. The development or existence of forest roads and the extent of forest road use are closely linked to the amount of activity, such as harvesting, which occurs in a specific area. Thus, the levels of harvesting or regeneration activities should also indicate the potential for road sediments to enter forest streams. While the rehabilitation of a poor forest road system might result in a significant reduction in road sediment production and delivery to forest streams, such activities are not necessarily reflected in data descriptive of the condition of forest stands.

Forests and Stream Flow

It is well established that the removal of forest cover increases the amount of stream flow. In the Southern United States, annual water yield as stream flow increases directly in proportion to the percentage of the area of forest cover removed. Bosch and Hewlett (1982), in a review of the literature, found that for every 10 percent of a watershed that is deforested, average annual stream flow increases 1.6 inches during the first year after tree removal. The greatest increases in stream flow due to forest harvest tend to occur during wet years. Conversely, the reforestation of previously cleared watersheds actually reduces total annual stream flow, and, during dry years, forests can significantly reduce stream flow totals.

It is important to understand the difference between total annual stream flow and peak or flood flow because the influence of forest harvest on these variables is significantly different. Total annual stream flow is the total volume of water produced by a stream in a year. Flood flow is the maximum discharge of a stream or river during an individual runoff event. Desert watersheds can produce tremendous flood flows very quickly but yield very low total volumes of water over the period of a year. Streams that maintain low but sustained flows over a long period of time can produce tremendous volumes of stream flow annually but may not produce large flood flows.

Forested watersheds in the Ouachita Mountains are particularly interesting regarding flood flows. With shallow soils, limited capacity to store water, seasons with intense and high amounts of rainfall, and well-developed sloping stream systems, high peak or flood flows are common. Research in the Ouachita Mountains has shown that forest removal does not increase the severity of the larger flood events that occur during the wet seasons when trees are not actively growing (Scoles 1992). During this period of time when soils are saturated they have little ability to store water. Trees that are not actively growing do not remove water from the soil and have little consequence on peak floods.

Forest removal does tend to increase the size and frequency of smaller peak flows of upland streams, especially during the drier portion of the growing season. At these times, forest removal causes soil moisture levels to remain higher than normal due to the reduction in tree interception and transpiration losses of water to the atmosphere.

Bottomland riparian forests play a unique and important role in the hydrology of streams on flood plains. Forest cover not only increases the amount of available water storage in flood plain soils; riparian and flood plain forests slow and spread flood waters and, thereby, attenuate or reduce the magnitude of flood peaks. The effect of flood plain forests is similar to that of a reservoir. The stabilizing effect of forest cover on stream banks and flood plain soils is also well recognized. Tree cover reduces the availability of flood-flow energy available to erode streambeds and banks and flood plain soils. Major changes in bottomland flood plain and riparian forest cover (land use) may therefore have implications for the rates of stream sedimentation, stream stability, and flooding.

Riparian Forest Functions

Riparian forests provide a number of important benefits to their associated stream systems (Miller 1986). We refer to these benefits as riparian forest functions, and they include the following: (1) Streambed and bank stability, (2) Stream temperature regulation, (3) Source of large organic debris, (4) Nutrient and pollutant sink, (5) Sediment reservoir or trap, and (6) Source of food for aquatic organisms.

Excellent technical reports are available detailing the functional relationships between riparian forests and stream ecosystems. These relationships need not be reviewed in this paper, and two of these functions have been briefly discussed previously. However, it is important to note that stream characteristics, for example, size, location, slope, and flow, interact and thereby determine for each stream which riparian functions dominate or are most important to stream health. For example, stream shade for temperature control is particularly important for smaller, cold-water upland streams but not as important for large, shallow and wide bottomland streams. Streambed and bank stability are not as critical for smaller, rocky, well-armored streams as compared to larger, meandering streams with deep unconsolidated bed and bank soils. The streamside management schemes needed for riparian forests to maintain important functions will therefore vary widely from stream to stream and across the landscape.

In Arkansas, upland or mountain riparian forests generally occupy narrow areas of the landscape adjacent to streams and rivers. Upland riparian forest types may or may not be significantly different from adjacent forest types and they often do not represent a large percentage of the total land area. Bottomland riparian and flood plain forests occupy narrow to very broad areas of the landscape. Bottomland riparian forest types are often distinct from adjacent forest types, and they may occupy a large percentage of the landscape. These facts have implications regarding the possible utility of FIA data as a tool for the evaluation of riparian forest functions and stream health.

WHAT FIA INDICATES ABOUT WATER QUALITY

Considering the variety of ways in which forests affect soil and water quality, the degree in which the location of forests with respect to bodies of water contributes to water quality, and the relatively short periods of time that disturbances to forests alters water quality, it is unlikely that FIA data, which was designed to measure large-scale, long-term trends in forest products, health, volume, and acreage, is well suited for indicating water quality within Arkansas. Since numerous nonforest as well as forest factors are responsible for the water quality in the State, FIA data cannot indicate what level of water quality exists in the State. However, due to the temporal nature of the FIA surveys, some information can be gleaned from this database, which can be used to indicate whether the general water quality in the state has improved or declined.

We foresee five areas of information in which FIA data may contribute to our understanding of temporal changes in water quality within the State. These specific areas are: (1) large scale changes in forest cover and land use, (2) changes in age distribution of forests, (3) information concerning harvesting activities as related to forest removals, (4) increases or decreases in riparian or wetland forest communities, and (5) changes in tree health or mortality, which may alter woody debris input to streams and bodies of water. In the following text, we focus on current and past surveys concerning these five attributes and how changes in these forest attributes may denote changes in water quality. It should be recognized that due to the differences in physiography, land use, demographics, etc., among regions within the State, not all of the survey information pertaining to the five attributes will be of similar applicability for indicating changes in water quality for a given region. Thus, examples will be presented or conclusions drawn for each of the five information areas where linkages between FIA data and water quality are strongest.

Large-Scale Changes in Forest Cover

As indicated earlier in this paper and by other sources (Moore 1988, Scoles and other 1995), undisturbed forests generally have low sedimentation rates and nutrient input in streams and other water bodies. Properly managed forests are considered to have less deleterious effects on water quality compared to more intensive land uses such as agricultural or urbanization. Thus, it seems likely that all other factors being equal, water quality in the State would generally be positively correlated with the amount of forest land in the State. Table 2 shows that the amount of forested land has increased from 16.6 million acres in 1978 to 18.8 million acres in 1995. Currently approximately 56 percent of Arkansas is forested compared to 49 percent in 1978. Although FIA data does indicate an increase in forest land, it gives no indication as to the land use of this area prior to afforestation. Considering the large variation of land uses in the State, it is difficult to determine if these increases in the forest land base would appreciably increase water quality in the State as a whole.

However, in the Delta region where the dominant land use is agriculture, increases in forest land would indeed suggest a reduction of agricultural land and, thus, a measurable increase in water quality. From 1978 to 1995, the amount of forest land in the Delta increased from 1.8 to 2.1 million acres, which represents an increase from 19 percent to 23 percent of the total land area in this region. This increase in forested land, presumably replacing agricultural land, would suggest that water quality within this region has either increased or at least stayed at the same level as it was in the prior surveys. It is possible that water quality has decreased if agricultural losses of soil, agricultural effluents, and/or water removals from existing agricultural lands have outpaced gains in water quality attributed to afforestation. Although the problem of assessing the current impact of specific nonforest land uses on water quality hinders our ability to use FIA data as a sensitive indicator of water quality in the State or a region as a whole, it seems likely that the increased amounts of forests in the State have had a positive impact on water quality.

Changes in Age Distributions of Forests

Increased amounts of forest canopy and litter reduce the erosion and nutrient movement from forest land areas to

Table 2—Forested and nonforested land by region during the last three FIA surveys in Arkansas

	Forested			Nonforested		
Region	1978	1988	1995	1978	1988	1995
	Acres					
Delta	1,827	1,899	2,110	7,664	7,592	7,106
Southwest	6,388	6,446	6,886	2,528	2,332	1,901
Ouachita	3,197	3,238	3,486	1,671	1,496	1,272
Ozark	5,205	5,730	6,326	5,507	4,458	4,237
Total	16,617	17,313	18,808	17,370	15,878	14,516

water bodies. Generally, the amounts of canopy and litter are at their lowest levels early in a forest's life after it has been regenerated through natural disturbances or planned manipulation. If a greater portion of Arkansas forests were at this early stage of development now rather than in the past, it would be possible that water quality influenced by forests would be reduced. We compared the area occupied by three broad age/size classes within each region over the last three surveys to evaluate if there had been any major shift in age distribution during this time. Although some variation among regions exists, forests in Arkansas have generally continued to mature during the last three surveys (table 3). The greatest increase in the area classified as sawtimber occurred in the Ouachita and Ozark regions. In 1995, approximately 61 percent and 42 percent of the timberland in the Ozark and Ouachita regions were classified as sawtimber compared to 52 percent and 40 percent in 1978. Increases in the amount of sawtimber acreage have also occurred in the southwest and Delta regions. However, the number of acres in seedlings and saplings has also increased as a result of an increase in reforestation. Thus, the proportion of total timberland classified as sawtimber has remained stable or declined slightly in these two regions.

Overall, there have been no large-scale changes in land area for the younger sapling/seedling-age classes. Instead the acreage of sawtimber has increased by 22 percent whereas the amount of forest land classified as poletimber or sapling/seedlings is similar to the 1978 levels. Consequently, there is no indication water quality has been reduced as a result of a change of stand or forest age in Arkansas.

Extent of Forest Management Activity

Although nutrient and sediment loss from stable, undisturbed forests is low, perturbations such as canopy removal, forest-floor disturbance, or tree removal either from natural or artificial sources, can increase the amount of these constituents in streams and surface water (Swank 1988, Shepard 1994). Research in Arkansas has verified that silvicultural practices such as tree harvesting can increase rates of nutrient and sediment loss. Although these rates are increased, the accelerated rates are generally short lived (Scoles and others 1995). The sediment and nutrient loads in streams from forest management activities have the potential for lowering water quality at least during a short period after forest harvesting. Forest roads are another source of sediment to streams. The amount of soil

Table 3—Timberlands in sawtimber, poletimber, and sapling/seedling size/age classes by region in Arkansas during the last three surveys

	Sawtimber			Poletimber			Sapling/seedlings		
Region	1978	1988	1995	1978	1988	1995	1978	1988	1995
	Acres								
Delta	1,080	1,181	1,279	465	442	365	245	238	447
Southwest	3,296	3,331	3,428	1,675	1,473	1,422	1,384	1,582	2,019
Ouachita	1,289	1,233	1,454	1,139	1,080	1,235	759	837	725
Ozark	1,319	1,706	2,351	2,194	2,775	2,464	1,659	1,174	1,194
Total	6,984	7,451	8,512	5,473	5,770	5,486	4,047	3,831	4,385

that can be produced and carried into streams from these forest roads can exceed the amount that is produced from silvicultural and harvesting activities (Scoles and others 1995).

FIA data has a limited ability to indicate what type of silvicultural practices is occurring or how many miles of roads are in use in Arkansas forests. The FIA data does report the volume of wood removed from Arkansas forests. Assuming that volume/area harvested was similar among inventory periods, harvested volumes should give an overall indication about the level of management activity in forests and forest road use. Annual net removals increased in all regions except the Ouachita. Removals increased by approximately 50, 9, and 33 percent respectively, in the Delta, Southwest, and Ozark regions but decreased by 32 percent in the Ouachita region (table 4). The increased rates of removals in the Delta and Ozarks should reflect a greater level of forest activities such as harvesting and forest road use. This intensification of forest management has the potential to increase nutrient and sediment yields above those generated at lower levels of forest harvesting and management. The amount of additional nutrients and sediments in water attributed to the actual harvesting activity is probably minimal and short lived if good forest practices are utilized. However, if additional forest road construction or degradation of forest roads have occurred as a result of this increased activity, longer term and larger scale yields would be possible.

It is likely that any deleterious effects either from increased levels of tree removal or road use/construction in the Ozarks or Delta have been offset by the increased forest land (table 2) and growing-stock volumes (table 5) within these regions. If increased removal rates would continue in these regions without a corresponding increase in forest land area and growing-stock volume, concern about a potential for a reduction in water quality might be warranted. However, given the increasing trends of forest land area and growing-stock volume, we do not foresee evidence that a decrease in water quality has occurred during the past 17 years. In the Ouachita region, where removals have decreased (table 4) while forested land area (table 2) and growing-stock volume (table 5) have increased, water quality related to forest management should be improving.

Table 4—Net annual growing-stock removals from 1978–88 and 1988–95 by Arkansas region

Region	1978–88	1988–95
	- - - - - - - - - *Million ft³*	- - - - - - - - -
Delta	44	66
Southwest	436	476
Ouachita	121	83
Ozark	62	83
Total	663	708

Table 5—Total growing-stock volume during the last three surveys by Arkansas region

Region	1978	1988	1995
	- - - - - - - - - - -	*Million ft³*	- - - - - - - - - - -
Delta	2,014	2,535	2,851
Southwest	8,348	8,322	8,833
Ouachita	3,404	3,370	4,108
Ozark	3,482	4,765	5,873
Total	17,248	18,992	21,665

Riparian and Wetland Forest Communities

Riparian and wetland forest communities often have a greater role in influencing and maintaining water quality and associated aquatic functions than do upland forest communities. These communities, due to the close proximity to bodies of water, provide carbon for primary consumers in the aquatic food chain, modify the climate of water, remove sediment/pollutants from water, and provide habitat for aquatic fauna. Thus, these communities deserve special attention in any evaluation of forest influence on water quality. As a result of their influence on water quality, any reduction in these forests or conversion to more upland communities through alteration of hydrology would have the potential for reducing water quality. The two forest types that are recognized and classified by FIA as wetland or riparian forests are the oak-gum-cypress and elm-ash-cottonwood forest types. Due to the small amount of land these forest types occupy in the Ozark and Ouachita regions (<7 percent) discussion concerning these forest types will be limited to the Delta and Southwest regions.

Amounts of forest land during the last three surveys in the riparian/wetland (oak-gum-cypress and elm-ash-cottonwood), loblolly pine, and other forest types are given in table 6 for the Delta and Southwest regions. The amount of forest in the oak-gum-cypress and elm-ash-cottonwood types has increased over the past three surveys in the Delta region. After a decrease in the Southwest region in 1988, the area of riparian/wetland forests has increased. The riparian/wetland forest has comprised between 68-69 percent of the forest land in the Delta since 1978. The increase in riparian/wetland forest acreage along with the maintenance of the proportion of forests of this cover type, again suggests that water quality should have remained the same or increased during the last three survey periods within the Delta region.

In the Southwest during 1978, this forest type comprised 19 percent, decreased to 16 percent in 1988, and finally increased to 17 percent of the forest land during the last survey period. The decrease in the riparian/wetland forests

Table 6—Timberlands in riparian/wetland (oak-gum-cypress and elm-ash-cottonwood), loblolly-softleaf pine and other forest types for the Delta and Southwest regions during the last three surveys

	Riparian/wetland			Loblloly-shortleaf pine			Other forest types		
Region	1978	1988	1995	1978	1988	1995	1978	1988	1995
	Acres								
Delta	1,266	1,295	1,427	68	86	144	491	517	540
Southwest	1,228	1,051	1,171	2,581	2,562	3,018	2,579	2,833	2,692

in the Southwest region between the 1978 and 1988 surveys may indicate a reduction in water quality at that time. It cannot be determined using this information if these forests were converted into agricultural production or upland forest-cover types. It does not appear that they were converted to loblolly pine, which is planted extensively in this region, because there was no increase in the loblolly-shortleaf pine area corresponding to the reductions in oak-gum-cypress or elm-ash-cottonwood forest areas. Regardless, riparian/wetland forest land area increased by 120,000 acres in the Southwest between the 1988 and 1995 surveys. Any potential reduction in water quality from the loss of these forests between 1978 and 1988 appears to have been partially mitigated with the increase in riparian/wetland forest area between 1988 and 1995. Therefore, at least in the short term, water quality in the Delta and Southwestern regions, as indicated by these forests, have remained similar or improved.

Woody Debris and Carbon Input from Forests

A large portion of the carbon input and fauna habitat for streams is derived from forests. Increased levels of mortality or reduction of health may indicate an increase in this input and a resulting change in water quality. We used the average annual mortality of growing stock and volume of rotten wood from each region during the last two surveys to determine if there have been any potential changes in woody input and, thus, water quality (table 7). Trends between the last two surveys are sporadic with mortality and volume of rotten trees each decreasing in three regions and increasing in one. This would appear to indicate, at least on a statewide basis, that the input of wood materials in streams or water bodies may have decreased during the last survey. However, linkages between this information and woody inputs to streams may be poor. The FIA does not indicate if mortality and rotten volumes consist of upland trees or riparian/wetland trees and where these trees occur in relation to the State's water resources. We believe that the changes in tree health and mortality, with the exception of possibly a 63 percent reduction of rotten tree volume in the Southwest, are not of a magnitude to have any immediate, harmful effect on woody input or water quality.

SUMMARY

Recognizing the limitations of FIA data as it concerns water quality, it is inappropriate to make an unequivocal conclusion concerning water quality within the State. However, the majority of the information we considered does indicate that water quality should have improved or remained the same within the State since the last survey. These improvements are directly related to the increase in forest area within the State and, specifically, in the Delta region.

In the Delta and Southwestern regions, modest increases in wetland/riparian forest types have occurred. These forests have a very direct influence on water quality of streams and rivers. Although timber removals and, thus, general forest management activities have increased within the State, the greater growing-stock volumes and the general maturing of the State's forest should minimize or eliminate any potential decrease in water quality related to intensifying of forest management. Thus, we see no decrease in water quality in the State related to the condition, quantity, or quality of the forests during the last survey compared to previous surveys.

Through our review of the FIA data, we recognized several ways in which FIA data could be improved to better evaluate relationships between the condition of the forests

Table 7—Average annual mortality of growing stock, and volume of rotten timber in Arkansas by region

	Average annual mortality		Volume of rotten timber	
Region	1978–88	1988–95	1988	1995
	Million ft^3			
Delta	31.5	29.2	53.6	33.4
Southwest	56.1	68.1	90.8	33.7
Ouachita	22.1	15.9	43.9	27.2
Ozark	32.4	27.9	98.1	101.3

in Arkansas and water quality. First, information concerning water quality could be improved if a more spatially intensive inventory could be initiated. Forests, such as wetland and riparian stands, which occur in close proximity to water bodies, wetlands, or head waters, will have a greater effect on water quality than forests that occur in other locations. Increasing the intensity of sampling would better quantify the character of these important forest types and locations.

It would also be beneficial to spatially link FIA data with other geographical and physiographical databases. For example, linking FIA data with hydrology information or an ecological classification system would increase our ability to delineate forest management/water quality relationships in specific watersheds or ecologically important areas. Linking soil information such as erosion potential or nutrient content with FIA data would better enable us to evaluate the impact of increased removals or forest activities on water quality.

Since effects from forest management and harvesting on nutrient and sediment input in streams are generally short lived, more frequent measurements of plots would also be beneficial. The majority of any water-quality effects from a large-scale increase in forest harvesting occurring within 2 to 3 years after a survey would be greatly reduced by the next survey completion. A decrease in the length of time between surveys would give a "real time" indication of potential changes in water quality related to Arkansas's forests.

REFERENCES

Beasley, R.S.; Miller, E.L.; Lawson, E.L. 1987. Chemical properties of soils and streams in natural and disturbed forest ecosystems in the Ouachita Mountains. Technical Completion Report Research Project G-1212-02. Arkansas Water Resources Research Center, University of Arkansas at Fayetteville. 93 p.

Bosch, J.M.; Hewlett, J.D. 1982. A review of catchment experiments to determine the effect of vegetation change on water yield and evapotranspiration. Journal of Hydrology. 55: 3–23.

Hewlett, J.D.; Doss, R. 1984. Forests, floods, and erosion: a watershed experiment in the Southeastern Piedmont. Forest Science. 30: 424–434.

Jorgensen, J.R.; Wells, C.G. 1986. Foresters' primer in nutrient cycling. Gen. Tech. Rep. SE-37. Asheville, NC: Southeastern Forest Experiment Station. 42 p.

Miller, E.L. 1986. Effects of forest practices on relationships between riparian areas and aquatic ecosystems. In: Proceedings, Annual Meeting Society of American Foresters: 172–179.

Miller, E.L.; Beasley, R.S.; Lawson, E.R. 1988. Forest harvest and site preparation effects on stormflow and peakflow of ephemeral streams in the Ouachita Mountains. Journal of Environmental Quality. 17: 212–218.

Miller, E.L.; Beasley, R.S.; Lawson, E.R. 1988. Forest harvest and site preparation effects on erosion and sedimentation in the Ouachita Mountains. Journal of Environmental Quality. 17: 219–225.

Miller, E.L.; Beasley, R.S.; Covert, J.C. 1985. Forest road sediments: production and delivery to streams. Blackmon, B.G., ed. In: Proceedings, Forestry and Water Quality: a Mid-South Symposium; Little Rock, AR; University of Arkansas at Monticello: 164-176. (Errata on Tables 3 and 4; corrected values on p. 16 of this document.)

Moore, J.W. 1988. Balancing the needs of water use. New York: Springer-Verlag. 267 p.

Patric, J.H.; Evans, J.O.; Helvey, J.D. 1984. Summary of sediment yield data from forested land in the United States. Journal of Forestry. 82: 101–103.

Scoles, S.R. 1992. Water yield, peak flow, and high flow response of a large forested watershed in central Arkansas to sustained forest harvest operations. M.S. thesis. Oklahoma State University. 222 p.

Scoles, S.R.; Anderson, S.; Turton, D.J.; Miller, E.L. 1995. Forestry and water quality: a review of watershed research in the Ouachita Mountains. OK. Coop. Ext. Water Quality Series. Circular E932. 29 p.

Shepard, J.P. 1994. Effects of forest management on surface water quality in wetland forests. Wetlands. 14: 18-26.

Swank, W.T. 1994. Stream chemistry responses to disturbance. In: Swank, W.T.; Crossley, D.A., Jr. eds. Forest hydrology and ecology at Coweeta. New York: Springer-Verlag: 339–358.

U.S. Department of Agriculture, Soil Conservation Service. 1989. Summary report 1987 national resources inventory. Statistical Bulletin Number 790. Iowa State University Statistical Laboratory. 36 p.